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A phenomenological retention tank model using settling velocity distributions

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ABSTRACT

Many authors have observed the influence of the settling velocity distribution on the sedimentation process in retention tanks. However, the pollutants' behaviour in such tanks is not well characterized, especially with respect to their settling velocity distribution. This paper presents a phenomenological modelling study dealing with the way by which the settling velocity distribution of particles in combined sewage changes between entering and leaving an off-line retention tank. The work starts from a previously published model (Lessard and Beck, 1991) which is first implemented in a wastewater management modelling software, to be then tested with full-scale field data for the first time. Next, its performance is improved by integrating the particle settling velocity distribution and adding a description of the resuspension due to pumping for emptying the tank. Finally, the potential of the improved model is demonstrated by comparing the results for one more rain event.

1. Introduction

Retention tanks (RTs) are used in many North American and European cities to reduce the impact of combined sewer overflows (CSO) on receiving water bodies. The goals pursued with RTs can vary from one design to another: intercepting the first flush of pollutants or the first hydraulic peak; carrying out primary treatment of the wastewater by solids separation; or retaining the maximum quantity of combined sewage before sending it back to the wastewater treatment plant (WWTP). Already in 1985, Lindholm was wondering whether the overall impact of those tanks on the receiving waters was positive. Actually, emptying the RTs could have a negative impact on the WWTP's treatment efficiency, potentially leading to a higher pollutant load to the receiving waters than from direct overflows. Since then, several theoretical studies have been conducted (e.g. Lessard and Beck, 1990; Bauwens et al., 1996; Lau et al., 2002; Vanrolleghem et al., 2005; Ahnert et al., 2009; Maruejouls et al., 2011). In all cases, the authors investigated the potential impacts of emptying RTs on the WWTP and highlighted the importance of analyzing the urban wastewater system as a whole to properly quantify the benefits of implementing RTs. Calabro and Viviani (2006) suggested that an important issue that remained to be dealt with is the effect of the RTs' emptying wastewater composition on the WWTP.

As integrated modelling is increasingly used in wastewater management, models to simulate the pollutants' behaviour in RTs become a necessity to predict the WWTP's influent quality. Indeed, settling is a major process in both RTs and WWTPs since particles carry a broad range of pollutants (Ashley et al., 2004). Two types of models have been developed to represent sedimentation processes in RTs. The first type uses Computational Fluid Dynamics (CFD) to describe the transport of water and particles (Stovin and Saul, 2000; Vazquez et al., 2008). CFD models are useful to optimize the

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shape of RTs but the time required to solve the equations does not allow their use in integrated urban wastewater management. The second type of models is phenomenological in nature: they represent the dynamics of water and particles in one dimension (Lessard and Beck, 1991; Frehmann et al., 2005). Since they can be used to optimize the design and operation of RTs in an integrated management context, this type of models was selected for our study. It is interesting to note that none of those phenomenological models has actually been validated with full-scale data (Kutzner et al., 2007). They strongly depend on one key characteristic of the particles: the average settling velocity (Vs). However, the average settling velocity is difficult to determine due to the large range of Vs found in combined sewage and an average value does not represent well the physical processes. As many authors have mentioned, the distribution of Vs is a factor that could have a large impact on the overall sedimentation process (Huebner and Geiger, 1996; Boxall et al., 2007; Saul et al., 2007), but it is rarely characterized.

The objective of this paper is thus to:

- implement the existing dynamic retention tank model of Lessard and Beck (1991) in a wastewater management modelling software to assess its performance against full-scale field data;
- improve that RT model by describing the settling process in a more detailed way and by implementing resuspension due to pump activation during emptying; and
- calibrate that upgraded model using full-scale field data.

2. Materials and methods

2.1. Measurement campaign

Intensive measurements campaigns were conducted on a selected urban catchment in Quebec City during the summers of 2009 and 2010. The 1.46 km^2 catchment is mainly residential with an average imperviousness of around 50%, a concentration time of 26 min and an estimated population of 5200.

The off-line RT was designed to allow an average of four overflows during the summer period (May 15th–September 15th). It has a volume of 7580 m^3 and is emptied by pumping after the transport capacity in the main interceptor to the WWTP is regained. The structure is divided in two parts: 1) a control chamber which allows the derivation of the water to the interceptor, the tank or the overflow pipe. This derivation is controlled by a lateral weir; and 2) the 7580 m^3 tank including a pumping well. Four operation phases are observed in a RT: filling, storage, overflow and emptying.

Since TSS is known as the main vector for pollutant transport in combined sewers, this study focuses on the variation of that variable within a rain event. Analyses were done according to Standard Methods (APHA et al., 2005). Characterisation of the settling of particles was carried out with the ViCAs protocol (Chebbo and Gromaire, 2009), both on composite and grab samples collected at the inlet (downstream of the control chamber's weir) and the outlet (downstream of the pumping well, in the pipe leading back to the control chamber) of the RT. The ViCAs protocol is well adapted to the sample volume requirements for analyses (Berrouard, 2010) (for more details, see Maruejouls et al., 2010, 2011). The ViCAs protocol consists in inserting a wastewater sample in a vertical PVC column (Ø 7 cm, height 60 cm) and collecting the mass of settled particles at the bottom of the column at various times during 24 h. A small numerical application allows calculating the cumulative mass distribution of Vs.

More than 20 events were sampled during the 2009–2010 campaigns. Analysis of the pollutant dynamics reveals a reproducible TSS load pattern for different events. At the inlet, the various pollutographs obtained reveal typical distinctive concentrations for most of the events. A peak of TSS concentration is mostly observed during the first minutes which, then progressively decreases (Fig. 1). This peak is caused by the wash-off of the pollutants accumulated on the watershed during the dry weather period between two rain events. Runoff transports those pollutants to the combined sewer. Finally, the TSS concentration reaches a threshold characterized by low concentration values (mostly lower than 100 g/m^3). It is due to the dilution of wastewaters by the rain water. Fig. 1 presents a typical TSS concentration time series

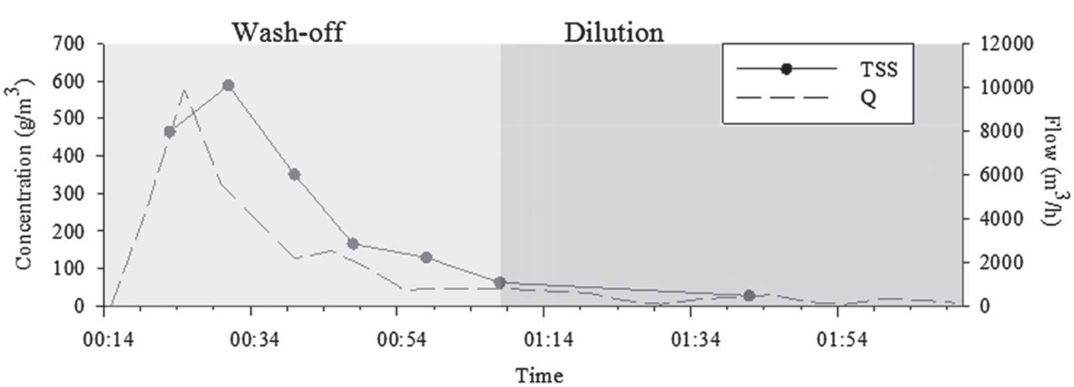

Fig. 1 – Typical RT inlet pollutograph showing the distinction between the wash-off and dilution periods (July 18th 2009 rain event).

during a rain event showing the distinction between wash-off and dilution periods. The method used to discriminate the two periods is explained below (paragraph 3.3.3.2).

During emptying, RT waters sent back to the WWTP can be split into three distinct phases: initial, middle and final phases, resulting in a U-shape TSS concentration profile. A typical RT outlet pollutograph is shown on Fig. 2. It is characterized by specific concentration ranges including two peaks (initial and final) and a quasi-constant TSS concentration during the middle phase, around 80 g/m^3 (for more details, see Maruejouls et al., 2010, 2011). To briefly summarize, the mass contained in the final phase is a result of the cleaning system activation (particles are pushed to the pumping well due to cleaning waters released at the end of emptying). A fraction of that mass still remains in the pumping well after the end of emptying. This fraction will constitute the mass contained in the initial peak of the next emptying. Finally, the mass contained in the middle phase corresponds to the particle mass not settled during the storage period.

Averages of 10 ViCAs of RT inlet waters are plotted on Fig. 3. Such curves can easily be made because all abscissa points (from each ViCAs test) are standardized, hence the y axis values can be used to calculate the averages and error bars. The "*wash-off*" curve includes a total of six ViCAs experiment results with a maximum TSS concentration of 1081 g/m^3, a minimum of 391 g/m^3 and an average of 745 g/m^3. For the "*dilution*" curve, four ViCAs were available. TSS concentrations of the samples reached a maximum of 286 g/m^3, a minimum of 66 g/m^3 and an average of 140 g/m^3. Symmetrical standard deviations are also plotted on Fig. 3 illustrating the distribution of ViCAs tests. Averages obtained with a lower number of ViCAs tests (like the "*dilution*" curve) can be highly impacted by an error due to a single ViCAs. Indeed, the larger ranges of the dilution curve are explained by a low number of ViCAs used for drawing the graph. This figure reveals that, for waters sampled within the concentration peak wash-off, the mass of particles with Vs below 1.6 m/h is 40%. If a typical settling velocity of 1.6 m/h for primary clarifier design is considered (Metcalf and Eddy, 2003), it means that 40% of the particle mass won't settle in such a clarifier, a typical result. For samples taken during the dilution period, this percentage rises to 70%, hence 70% of that mass will pass such a primary clarifier.

The pollutograph data will be coupled with the results from Fig. 3 to allow the fractionation of the TSS. This fractionation method is detailed in paragraph 3.3.3, below.

2.2. Lessard and Beck (1991), original model

As far as the authors know, the Lessard and Beck dynamic model is the only one modelling the various processes controlling the pollutant behaviour in RT. This RT model is based on one-dimensional ordinary differential equations of the mass balance. It allows simulating settling processes using two particle classes and transport of conservative pollutants (*i.e.* non-settleable COD and VSS, NH_4 or NO_3) in an off-line RT. The model includes twelve parameters and thirteen state variables. Eq. (1) presents the water mass balance where the change in water volume (V in m^3) depends on the difference between inflow and outflow (Q_{in} and Q_{out} in m^3/h). TSS behaviour is represented by two state variables which are the settleable and non-settleable SS concentrations. For each of these fractions, Eq. (2) is applied: the change of the concentration in the tank (dC/dt in $g/m^3/h$) is a function of inflow (Q_{in}), TSS influent concentration (C_{in}), concentration in the tank (C) and the loss by settling (*Settling* in $g/m^3/h$). The settling term only applies to the settleable SS fraction.

$$\frac{dV}{dt} = Q_{in} - Q_{out} \quad (1)$$

$$\frac{dC}{dt} = \frac{Q_{in}}{V} \cdot (C_{in} - C) - Settling \quad (2)$$

The model structure includes four flow conditions: filling, storage, dynamic settling (overflow) and emptying. Depending on these conditions, different equations are proposed to describe settling:

- *Filling*: this condition is met when water flows in and the outflow equals zero. The settling term is active when the water level rises above a pre-defined height. The idea is to reproduce the resuspension of particles due to turbulence within the first minutes of the inflow. The larger the tank is, the lower that height value will be set to. Settling is first

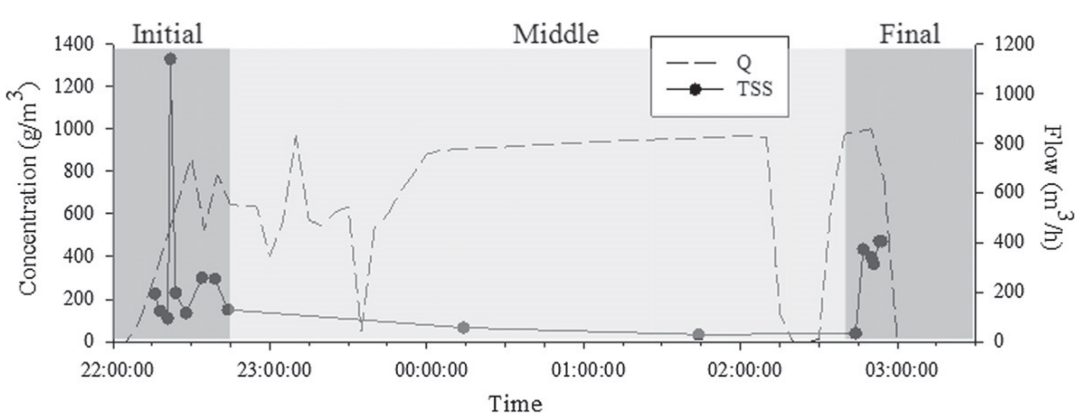

Fig. 2 – Typical RT outlet pollutograph showing the distinction between the initial, middle and final phases (June 6th 2010 rain event).

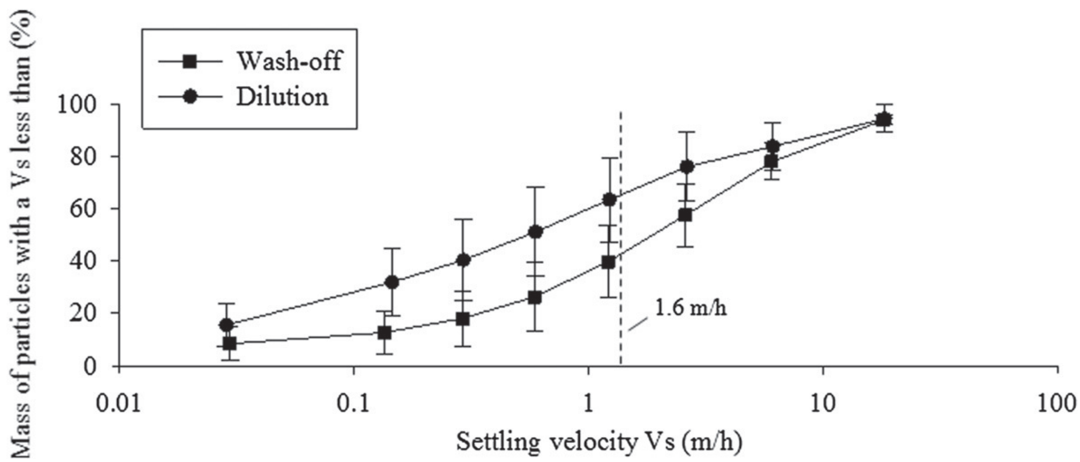

Fig. 3 – Average Vs distributions associated with inlet waters collected during the wash-off peak or dilution period.

order in the TSS concentration with a removal rate parameter (with unit h^{-1}).

- *Quiescent time*: this condition is met when waters are stored between the end of filling and the beginning of emptying. Within the first time step of calculation, all settleable particles are removed from the bulk volume. No settleable particles remain in suspension after that phase.
- *Drawing*: this condition is met when the tank is emptying and no waters flow into the RT. The model first withdraws the water from the bulk (without any settleable SS) then, reaching a set water level, all mass contained in the sludge is mixed with the bulk volume. Thus, only two concentration values can be calculated at the output. Settling is simulated according to a Vs parameter (in m/h).
- *Dynamic settling*: it happens under overflow conditions, i.e. when the inflow and the outflow are simultaneously active. The behaviour of the tank is described in a very similar way as a primary settler. Settling is a function of a settling velocity parameter and a scouring term (in m/h). This last term aims at reproducing resuspension by decreasing the settling velocity of particles.

3. Results and discussion

3.1. *Lessard and Beck model implementation*

The model was implemented in WEST (Vanhooren et al., 2003), a simulation software for WWTP management. For verification, simulation results obtained by Lessard and Beck were checked with WEST simulation results as shown on Fig. 4.

With regard to the hydraulic behaviour, the volume before overflow is welldescribed, apart from a small deviation after the first drawing. The volume reached is a little bit higher than the one obtained by Lessard and Beck (1991). Concerning the TSS concentrations, one can note a difference of about 500 g/m^3 between them. It is caused by the difference in volume, *i.e.* at the end the water volume is so low that a little variation on volume has a big impact on the concentration, but the mass of pollutants extracted by the pumps remains the same as in Lessard and Beck (1991). The implementation in WEST is thus found to agree.

3.2. *Lessard and Beck model simulation using full-scale data*

Until now, that model has never been confronted with full-scale field data, thus, its performance has never been assessed. Results for the simulation of the July 27th, 2009 rainfall event are presented in Fig. 5. The volume reached was 4064 m^3 (54% of tank capacity). The pumped outflow is rather constant except for the final phase where a sharp increase is observed. The final concentration peak occurs during this hydraulic peak, thus TSS loads to the WWTP is increased considerably. The volume fraction at which resuspension starts due to cleaning system activation at the end of emptying corresponds to the last 100 m^3. Since the emptying is controlled by pumps, the pumped outflow is an input to the model.

As expected, the model is able to reproduce the observed hydraulics (Fig. 5a). Settling within the storage tank is also quite well reproduced by the model: the measured and simulated middle phase concentrations are similar (around 70 mg/l), but detailed simulation results show that no sedimentation occurs during the middle phase of the emptying (Fig. 5b). Indeed, the TSS concentration observed during the middle phase of the emptying (low concentration period), decreased from 73 to 54 g/m^3, whereas the simulated TSS concentration remains constant. The concentration decrease is observed for all sampled events and can be quite large for many events. An average carried out on fifteen sampled events shows a decrease from 210 to 100 g/m^3. Moreover, the typical U-shape cannot be reproduced, especially with respect to the initial concentration peak after the start of emptying. As mentioned earlier, the mass associated with that phase corresponds to the particles remaining in the pumping well from the previous event.

Modelling settling/resuspension processes due to the activation of pumps will thus constitute the first part of the model upgrade, aiming at accurately simulating the first TSS concentration peak. The second part will deal with giving more details on the Vs distribution to enable the model to describe

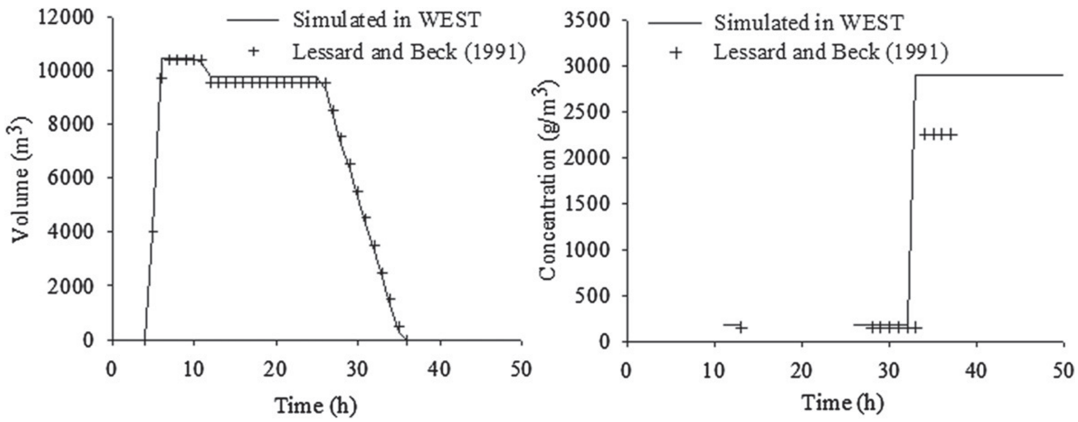

Fig. 4 – Comparison of results from the Lessard and Beck (1991) model and those obtained after implementation in WEST: (a) hydraulic behaviour; (b) outlet TSS concentration.

settling during the storage period and then to smoothen the outlet TSS concentration dynamics.

3.3. *Model upgrade*

The original RT model was upgraded on two main points: (1) adding a pumping well model allowing the simulation of particle behaviour at the activation of the pumps; (2) adding a third particle class to improve the model performance. These modifications will be developed below.

The model scheme of the RT/pumping well system is shown in Fig. 6. It allows the emptying to be controlled by pumps, settling/resuspension processes and transport of conservative pollutants.

3.3.1. *Retention tank model description*

With regards to TSS concentrations for both the inlet and the outlet, one layer was found sufficient to reproduce the processes occurring within the tank, described as a homogeneous tank. This layer, called "*clar*", is the clarified volume. No volume needs to be defined for the sludge compartment, since the sludge height is negligible compared to the water height (Eq. (4)). The mass accumulation at the bottom of the tank is the sum of the masses of the different particle classes. That mass is re-suspended when the cleaning system is activated at the end of emptying, and then particles are entirely transferred to the pumping well (Eq. (6)). The soluble pollutants (not shown in the presented study but taken into account in the developed model) are transported by inflow/outflow. The RT is hydraulically connected to the pumping well: the water level is assumed to be the same in both tanks at any time, considering that the "*Minimum water level*" is the height zero.

The hydraulic equations used for the RT/pumping well, are the same as those of the original model (Eq. (1)). For simplicity, the time argument has been omitted from all terms. The mass balances of the clarified volume and the sludge mass are:

$$\frac{dM_{clar,j}}{dt} = Q_{in} \cdot C_{in,j} - (Q_{out} + Q_{over}) \cdot C_{clar,j} - Sett_j + R_{RT,j} \quad (3)$$

$$\frac{dM_{sludge,j}}{dt} = Sett_j - R_{RT,j} \quad (4)$$

Where $M_{clar,j}$ and $M_{sludge,j}$ (g) are the pollutant masses for the particle class j in the clarified volume and in the sludge; Q_{in},

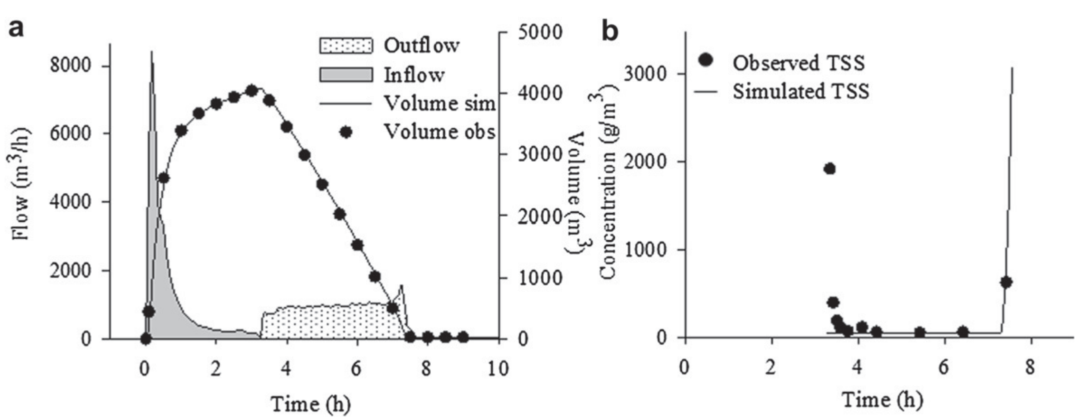

Fig. 5 – Simulation results for the July 27th, 2009, rainfall event using the original model: (a) hydraulic behaviour; (b) outlet TSS concentration.

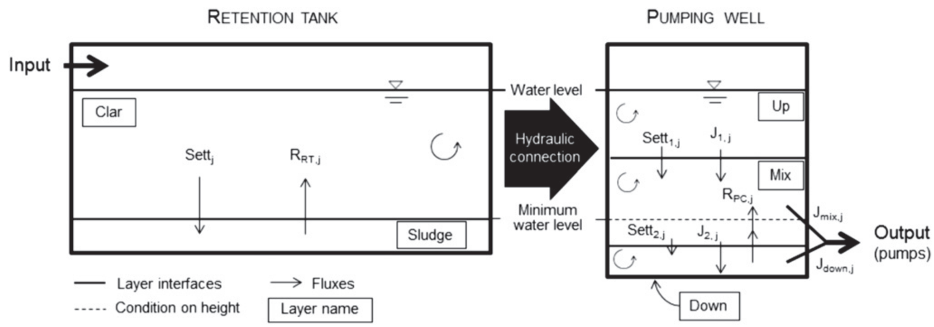

Fig. 6 – Proposed retention tank/pumping well model.

Q_{over} and Q_{out} (m^3/h) are respectively the inflow, the overflow and the outflow. $C_{in,j}$ and $C_{clar,j}$ are the TSS concentrations in the influent and clarified volume for the particle class *j*. Concentrations in each layer are equal to the mass in the layer for a class *j* divided by the volume in that layer ($C_{Layer,j} = M_{Layer,j}/V_{Layer}$). $Sett_j$ and $R_{RT,j}$ are the terms describing the particles' settling and resuspension, they are detailed below:

$$Sett_j = C_{clar,j} \cdot Vs_j \cdot A \quad (5)$$

$$R_{RT,j} = k_1 \cdot M_{sludge,j} \cdot a_1 \quad (6)$$

Vs_j (m/h) is the Vs for the particle class *j*; A (m^2) represents the tank surface; k_1 is the first order coefficient controlling the resuspension velocity and is set at 8 h^{-1} by default; a_1 is a Boolean state variable equal to 1 when the cleaning cells are releasing water.

3.3.2. *Pumping well model description*

The pumping well model includes three layers called "*Up*", "*Mix*" and "*Down*", which are described as homogeneous tanks. Through the hydraulic connection, waters from the tank can flow either in the "*Up*" layer or in the "*Mix*" layer depending on the water level conditions. For each layer, the dynamics of the pumping well volume evolution is described by Eq. (1) when this layer is fed, which is depending on the water height. The mass balance equation of the matter contained in "*Up*" layer is switched on when the water level reaches it (Eq. (7)). Particle settling is active at any time, during filling as well as during storage and emptying. The water volume remaining at the end of an event is represented by the "*Minimum water level*". When the pumps start working, particles remaining in the "*Down*" layer (including a fraction settled within the minimum volume between two events) will be re-suspended in the "*Mix*" layer according to a first order process (Eqs. (8), (9), and (16)). The "*Down/Mix*" interface is located under the minimum water level. Thus, settling can occur between two consecutive events. That "*Mix*" layer represents the maximum volume influenced by the resuspension, thus, re-suspended particles cannot go in the "*Up*" layer. The outflow conveyed through the pumps includes a variable ratio between flows from the "*Mix*" and the "*Down*" layers (Eqs. (12), (13), and (17)). The mass balance equations are as follows:

$$\frac{dM_{Up,j}}{dt} = (Q_{in} \cdot C_{in,j} - J_{1,j} - Sett_{1,j}) \cdot a_2 \quad (7)$$

$$\frac{dM_{Mix,j}}{dt} = Q_{in} \cdot C_{in,j} \cdot (1 - a_2) - J_{Mix,j} + J_{1,j} - J_{2,j} + Sett_{1,j} \cdot a_2 - Sett_{2,j} + R_{PW,j} \quad (8)$$

$$\frac{dM_{Down,j}}{dt} = J_{2,j} - J_{Down,j} + Sett_{2,j} - R_{PW,j} \quad (9)$$

Where $M_{Up,\ j}$, $M_{Mix,\ j}$ and $M_{Down,\ j}$ (g) are the particles' masses contained in each layer for particle class *j*; a_2 is a Boolean state variable permitting to activate the terms. It equals 1 when the water level rises above the "*Mix*" layer and 0 when the water level is below the "*Mix/Up*" interface. $J_{1,\ j}$ and $J_{2,\ j}$, and $Sett_{1,\ j}$ and $Sett_{2,\ j}$ (g/h) are, respectively, the mass fluxes and the settling fluxes between the "*Up*" and the "*Mix*" layers for particle class *j*. Since the RT and the pumping well are connected by the "*Up*" and "*Mix*" layers, $J_{1,\ j}$ and $J_{2,\ j}$ represent the layer interface fluxes caused by the pump outflow. The pumping well water quantity and quality are equal to those transferred at each layer interface $J_{Mix,\ j}$ and $J_{Down,\ j}$ (g/h) are, respectively, the outlet fluxes for the "*Mix*" and the "*Down*" layers for particle class *j*. The sum of those two fluxes for all particle classes is the effluent of the model. $R_{PW,\ j}$ represents the resuspension flux between the "*Down*" and the "*Mix*" layers for particle class *j*. All fluxes are detailed below:

$$J_{1,j} = Q_{out} \cdot C_{UP,j} \quad (10)$$

$$J_{2,j} = Q_{out} \cdot C_{Mix,j} \cdot (1 - a_{Mix}) \quad (11)$$

$$J_{Mix,j} = Q_{out} \cdot C_{Mix,j} \cdot a_{Mix} \quad (12)$$

$$J_{Down,j} = Q_{out} \cdot C_{Down,j} \cdot (1 - a_{Mix}) \quad (13)$$

$$Sett_{1,j} = C_{Up,j} \cdot Vs_j \cdot A \quad (14)$$

$$Sett_{2,j} = C_{Mix,j} \cdot Vs_j \cdot A \quad (15)$$

$$R_{PW,j} = k_2 \cdot M_{Down,j} \cdot (1 - a_2) \quad (16)$$

k_2 is the first order coefficient controlling the resuspension and is set at 10 h^{-1} by default. a_{Mix} (–) is a variable fraction term allowing the fractionation of "*Mix*" and "*Down*" pollutants in the outlet flux. The governing equation is:

$$a_{Mix} = (1 - \exp[-\alpha \cdot MAX(t - t_{Pstart}, 0)])/2 \quad (17)$$

T_{Pstart} (*h*) is the time when the pumps are activated. It permits having an exponential variation of the pollutant fractions, i.e.

when the pumps are started a_{Mix} tends to 0, when $t{-}t_{Pstart}$ tends to infinity, a_{Mix} tends to 0.5. Thus, a higher fraction of the "*Down*" layer pollutant is pumped at pump activation. α is a coefficient allowing setting the fraction variation rate, and is set to 0.002 h^{-1} by default. Physically, introducing Eq. (17) follows the assumption that, when the pumps are activated, the sludge closest to the pumps' inlet is extracted first. Then, as time goes by, the sludge is harder to extract due to the larger distance from the pumps' inlet, therefore a larger outflow fraction has a quality equal to the "*Mix*" volume.

To represent the particles first emptied within the initial phase, which are coming from the previous event, it is necessary to set a mass as an initial condition. This initial mass has an important impact on the simulation since it determines the maximum value reached by the initial peak. The following example shows the sensitivity to that initial condition: for a simulation set with an initial mass of 50 kg, the maximum TSS concentration is 2000 g/m^3, whereas for an initial mass set to 25 kg, the TSS concentration will only reach 1200 g/m^3.

3.3.3. *Particle classes*

In Lessard and Beck (1991) different equations are used to describe settling under different flow conditions. During dynamic settling, which corresponds to overflow conditions, an average Vs is used; during filling the settling velocity is controlled by a first order removal rate constant (h^{-1}), while within the storage phase settleable particles are just totally removed (as seen in paragraph 2.2.). It means that the correct removal rate cannot be assessed by measurement since its physical sense is not clear. But in fact, Vs can be estimated with reasonable precision from for instance ViCAs data. Thus, in the upgraded model, Vs is used for the whole simulation in all conditions. However, the observations clearly show that it is necessary to add another particle class with different settling properties. Indeed, the original model only uses two particle classes whereas the measurement campaign highlighted three main particle behaviours. A first one with a very high Vs allowing the particles to settle within the first minutes after entering the tank, *i.e.* mainly sand contained in the runoff. A second class with a Vs that allows settling over several hours. The third class settles very slowly, if at all. Additional classes could be added as field data are obtained, but keeping the model simple is pursued as well.

Inspired by the work of Vallet (2011) the TSS concentration fractionation method includes 3 parts: (1) starting from the ViCAs curves to define the class boundaries; (2) determining

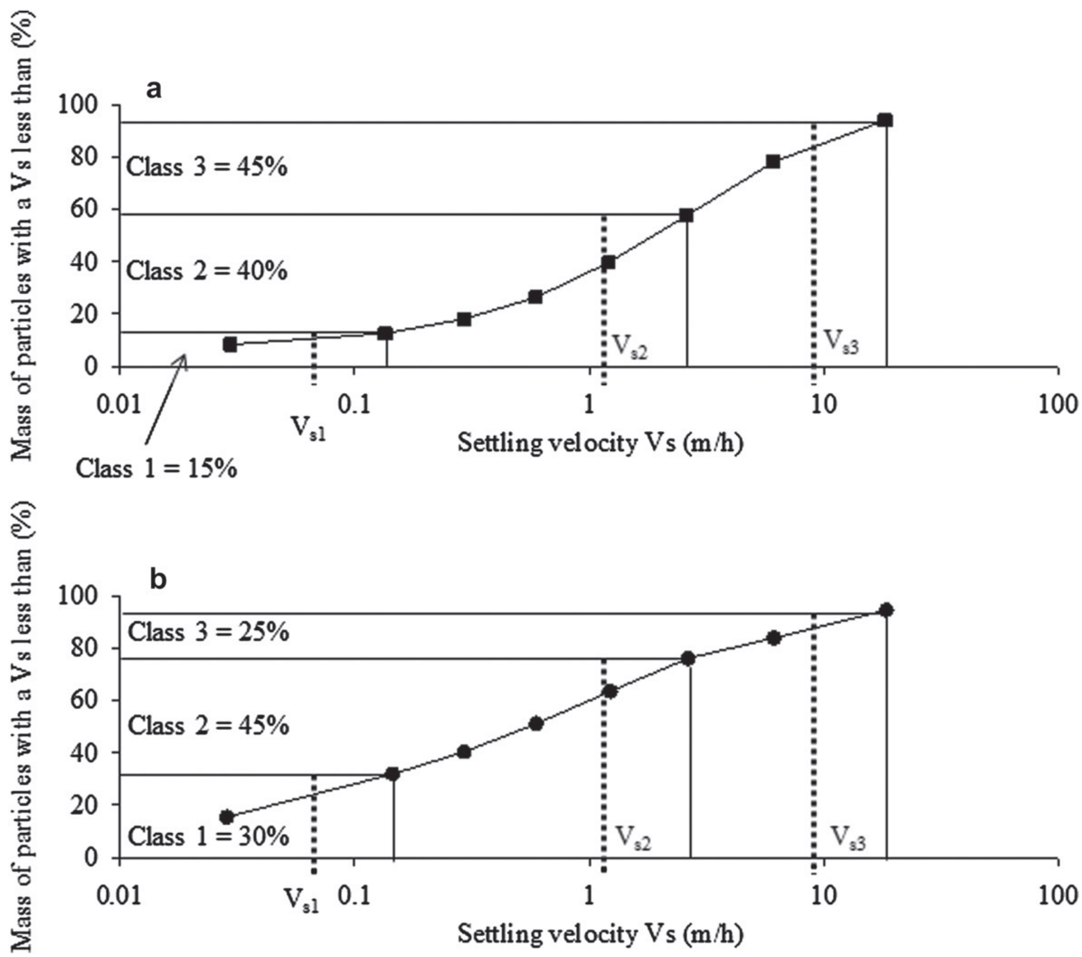

Fig. 7 – ViCAs Vs distribution fractionation enabling particle class determination: (a) Vs distribution for the wash-off period; (b) Vs distribution for the dilution period.

Table 1 – Vs particle classes chosen for the input of the model.

Classes	Vs (m/h)	Fraction of particles within the wash-off period (%)	Fraction of particles within the dilution period (%)
1	0.075	15	30
2	1.175	40	45
3	8.75	45	25

the TSS concentration peak boundaries to apply the optimal fractionation (within the wash-off or dilution period); and (3) linking the particle classes to a time series of TSS data.

3.3.3.1. *ViCAs fractionation.* The determination of the distribution of TSS over particle classes with different Vs is possible thanks to ViCAs curves obtained at the inlet (Fig. 3). The distribution of settling velocities of particles in waters from the influent of the RT needs to be split in two: one distribution representing the Vs distribution during the wash-off and the other one representing the Vs distribution during the dilution period. The method to fractionate the ViCAs curves into sedimentation classes and to define the Vs particle classes is presented in Fig. 7. For both ViCAs, the Vs distribution is the same, only the fractionation of the particle mass over the three classes changes. Various fractionations were tried, but the ones presented in Fig. 7 best fit the settling process for combined sewer influent of our case study. Once the fractionation is performed, the arithmetic average between the two vertical boundaries of a class gives the Vs to be attributed to the class.

The calibration of that fractionation was made by moving the horizontal and vertical boundaries (and by extension the Vs), which changes the particle mass fraction and the corresponding Vs for each class. Finally, Table 1 presents the best particle classes with their corresponding Vs and mass fractions.

3.3.3.2. *Peak boundary definition.* Using the above values, TSS is fractionated into wash-off and dilution Vs particle class distributions. Determining the end of the wash-off period is difficult since all events have very different behaviours. Indeed, the intensity and the duration of the peak depend on the rain characteristics, the antecedent dry weather period, and the water quality and quantity in the collector pipe. Here, it has been chosen to focus on the TSS concentration. Since Maruejouls et al. (2011) showed the correlation between the concentration and the Vs distribution, the selected method is based on the same assumption. Indeed, the authors observed that the higher the TSS concentration, the bigger is the particle mass fraction with high Vs. Thus, for TSS concentrations higher than 100 g/m^3 (typically observed within the wash-off peak), the ViCAs fractionation used is the one for the wash-off period, whilst for TSS concentrations lower than 100 g/m^3 the ViCAs fractionation from the dilution period is used. The result is shown on Fig. 1, where the two periods are distinguished using that assumption.

3.3.3.3. *Particle class distribution.* Table 2 explains the fractionation of the influent TSS concentration in particle classes with different Vs. Two different Vs distribution profiles are used to fractionate the influent. On the left table, time series samples are presented with TSS concentrations denoted A, B, C…N sampled at times 1, 2, 3…n. The right table presents the same time series after fractionation; the light grey area corresponds to a fractionation for the "*wash-off*" period where the mass fractions are: class 1 = 15%, class 2 = 40% and class 3 = 45%; and the dark grey one for the "*dilution*" period with the mass fractions: class 1 = 30%, class 2 = 45% and class 3 = 25%.

3.3.4. *Simulation results and discussion*

The results of two simulations using full-scale data are presented here. Many events couldn't be used in the modelling work because of some lack of data in the time series sampled. Indeed, sampling all phases of an event (inlet with the wash-off and dilution phases, outlet with the three phases) is a difficult exercise, only two sampled events were sufficiently complete for use in modelling. Moreover, this paper is about proposing a new RT model and showing its potential after calibration. More data will be used when performing validation.

Fig. 8 shows results from a simulation carried out with the same data of the July 27th 2009 event, the same used with the original model in paragraph 3.1. Since the hydraulic inputs of the model are the inflow and the pumped outflow, the simulated volume of the system fits the data perfectly. It is more relevant to show the layer volumes in the pumping well in order to understand what happens in terms of hydraulics.

After a manual calibration, the "*Down*" and "*Mix*" volumes have been found optimal to 11 and 80 m^3 respectively (5 and 38% of the pumping well maximal capacity). The minimum volume in the pumping well has been set to 13 m^3 (corresponding to a water level of 30 cm) and the cleaning system is activated when 100 m^3 remained to be withdrawn. RT and pumping well surfaces are parameters which are set according to the structure dimensions, respectively 1550 and 36 m^2 in the present case study.

The hydraulic behaviour in the pumping well is as expected (Fig. 8a). The "*Down*" volume is constant during the whole time and is equal to 11 m^3. The "*Mix*" layer reaches its

Table 2 – Fractionation method of the influent TSS concentration using 2 different Vs distribution profiles.

Time		TSS		
		Class 1	Class 2	Class 3
1	Wash-off	15*A	40*A	45*A
2		15*B	40*B	45*B
3		15*C	40*C	45*C
4		15*D	40*D	45*D
5	Dilution	30*E	45*E	25*E
6		30*F	45*F	25*F
7		30*G	45*G	25*G
n		30*N	45*N	25*N

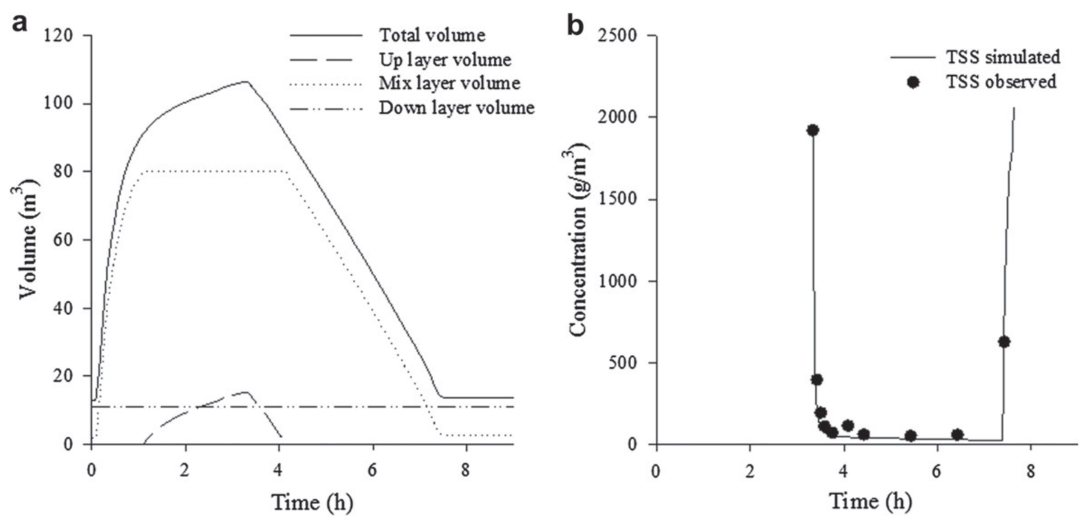

Fig. 8 – Simulation results of the July 27th, 2009 event: (a) pumping well hydraulic behaviour; and (b) outlet TSS concentration.

maximum capacity of 80 m^3. When that maximum is reached, the "*Up*" layer begins to be filled until the maximum capacity of the tank.

The total initial mass was set to 45 kg and was distributed as follows: 14.5 kg for the Vs_1 class, 22.5 kg for the Vs_2 class and 8 kg for the slowest class Vs_3. The particles still present in the pumping well between two events correspond to particles with a high Vs that were washed from the RT at the end of the previous emptying. Consequently, the fractionation of that initial mass must be different from the one used as inflow to the RT. Particle classes V_{s1} and V_{s2} are entirely contained in the "*Down*" layer since they have high Vs, whereas particle class V_{s3} is equally fractionated between the "*Down*" and "*Mix*" layers. Since this initial condition is due to the previous event and landuse characteristics, the best way to set it consists in running a start-up simulation with data from the closest sampled event available and to reuse the masses obtained in each layer at the end of the run as initial conditions. Ideally, measurements should be carried out in the pumping well for the best assessment of the initial conditions on the mass. Finally, a validation should be carried out using two consecutive events assessing the models' ability to represent the mass remaining in the pumping well between two emptyings.

Regarding the outlet TSS concentration, the results obtained in Fig. 8b are in good agreement with the observed data. The emptying of the pumping well at the beginning shows the observed concentration peak. Within the middle phase, the observed data show a TSS concentration that is decreasing slowly from 73 g/m^3 to 54 g/m^3 (as already discussed in paragraph 3.2). This is due to continued settling during

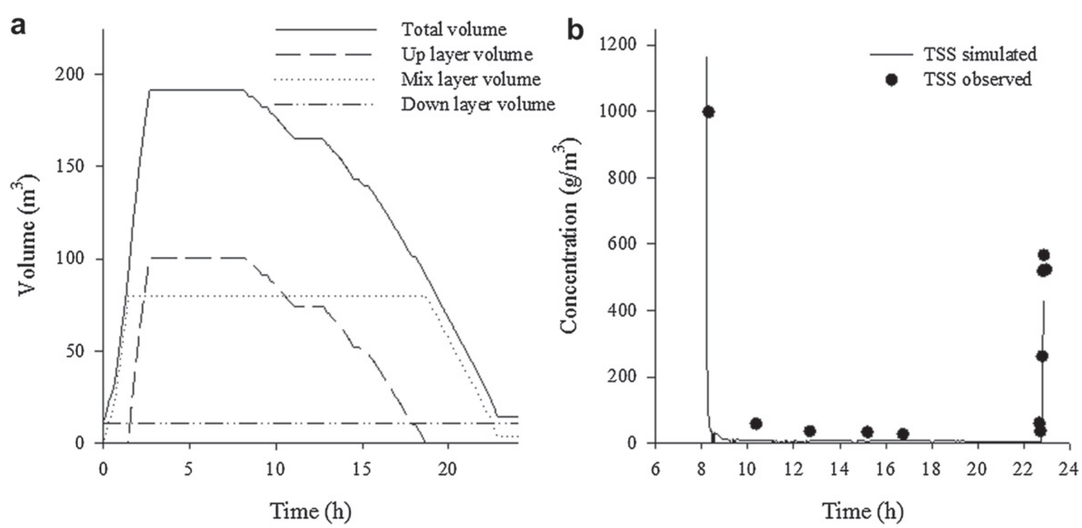

Fig. 9 – Simulation results of outlet TSS concentration for the September 27th, 2009 event: (a) pumping well hydraulic behaviour; (b) outlet TSS concentration.

emptying. The simulation results present the same behaviour within that phase, decreasing from around 65 g/m^3 to 25 g/m^3.

For the September 27th 2009 event, the "*Up*" layer and total volume are reached, and overflow occurs between 2.5 h and 8 h (Fig. 9a). The initial mass introduced in the "*Down*" and "*Mix*" layers is 29.5 kg in accordance with the fractionation method presented before. Generally, the TSS concentration within the middle phase is slightly underestimated by the model, but in this event, the role of settling during the emptying phase is stronger. Furthermore, when pumps are stopped, then the outflow is nil and the simulated TSS concentrations equal zero. Finally, using more events, the simulation of the last TSS concentration peak could be improved by additional calibration of the first order coefficient k_2 which controls the resuspension velocity, but the results obtained were found satisfactory (Fig. 9b).

4. Conclusion

Specific ranges of settling velocity distributions were observed at the retention tank inlet. They are linked to the dynamics of the TSS concentrations associated with different operating phases of a retention tank. To adequately model the observations, the Lessard and Beck (1991) retention tank model was for the first time tested with full-scale field data and then improved by integrating information on the settling velocity distribution as well as settling/resuspension processes occurring in the pumping well. The improved model has been successfully tested with full-scale data showing its potential. However, more studies are needed to assess its performance by:

- calibrating and validating the model to find the best initial conditions for the mass of the different particle classes by using full-scale data sampled during two consecutive events;
- performing more ViCAs tests on the case study (especially for the dilution phase) to find the optimal ViCAs templates to use as model input;
- carrying out a more detailed selection of the particle classes;
- validating the model using different events; and
- integrating organic matter and nutrients in the model, because this is of interest to predict the influent of the wastewater treatment plant.
- implementing a new fractionation model allowing to link the typical WWTP state variables to the retention tank model state variables.

Such study brings new information about the emptying wastewater quality and allows thinking its management in a different way, taking into account the wastewater quality of those three phases. Since the hydraulic shock under wet weather flow conditions is known as an important factor of the WWTP yield degradation, it could be conceivable to route the initial and final phases to the WWTP while the middle phase is discharged directly to the receiving body. Furthermore, in an integrated urban wastewater management context, modelling can be useful for sizing structures such as for managing the emptying sequences taking into account the interactions between the different physical subsystems. Indeed, managing many retention tanks on a combined sewer could be done by diluting the final and initial phases with the middle phase of other retention tanks. Wastewater quality could in this way be more homogeneous leading to less important load shocks at the WWTP. In that context it is expected that using particle classes with different Vs in models for urban wastewater management will lead to improved predictions of WWTP influent water quality.

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